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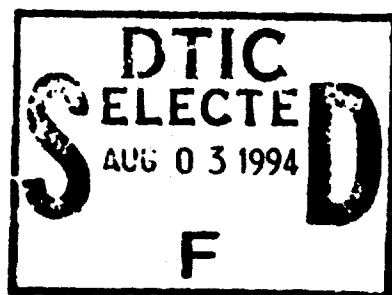
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STATIONARY DETONATION

- USSR -

by B. V. Voytsekhovskiy



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STATIONARY DETONATION

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(Presented by Academician M. A. Lavrentiyev
14 September 1959).

In connection with the great velocity of propagation of the detonation wave, which reaches several kilometers per second, it is customary to regard the phenomenon of detonation as a millimicrosecond process.

If in a channel conditions were created under which the original gas mixture would be continuously fed in before the front of the detonation wave, the phenomenon could be transformed into a stationary-state process. A model installation diagram, in which a stationary detonation was obtained, is represented in Fig. 1.

The front of the detonation wave constantly spreads in one direction along the circumference of the ring-shaped channel 1. The original gas mixture enters into the channel in a radial direction through the inner wall. The detonation products are removed from the channel through the opposite wall. The photographing of the detonation in the ring takes place through the glass, which represents the upper wall of the channel. After the front of the detonation wave passes by one of the points on the ring, the consumed mixture begins immediately to be pushed back by the original gas mixture being fed in. The unconsumed gas occupies the sector of the ring-shaped wedge with the apex behind the front and the base coinciding with the same front, in the case of a single-headed detonation. In the case of several fronts going in the same direction, a front of the original mixture coming into the installation will spread out behind the preceding one. The diagram of disposition of fronts in the ring-shaped channel is represented in Fig. 2.

The initiation of the mixture in the ring-shaped channel was carried out at one of the points on the circum-

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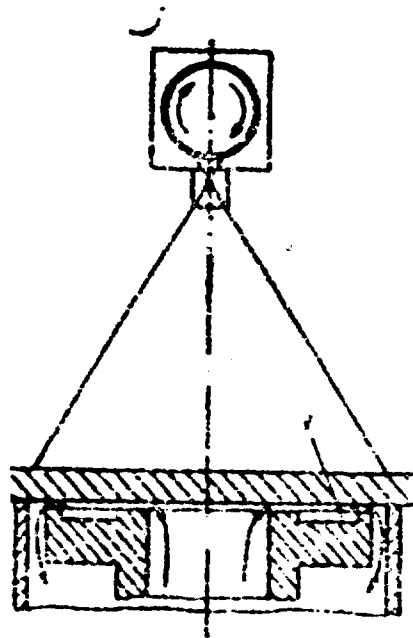


Fig. 1. Model Diagram of installation for observation of stationary detonation. 1 is the ring-shaped channel.

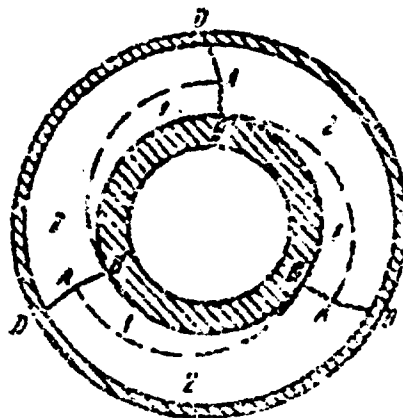


Fig. 2. Diagram of disposition of the fronts of a stationary detonation. 1 - the original mixture, 2 - detonation products.

ference synchronously with the opening of the photorecorder. After a full rotation of the film in the photorecorder, the shutter was closed to avoid a superposition of the photographs. If special adjustments are not made the detonation wave spreads simultaneously in various directions from the place of initiation.

The detonation waves collide on the opposite side of the ring. A break of the detonation wave through the feeding nozzle into the reservoir filled with the original mixture can then occur. The problem of eliminating the possibility of reverse breaks presents considerable technical difficulties. It is solved by selecting specially designed feeding nozzles and by establishing the necessary regime of pressure.

After the collision of two contrary detonation waves, a multiplication of the number of the fronts takes place over a certain period of time, and then a stable process of frequent collisions between detonation waves sets in. In order that a stationary ring detonation may be formed, it is necessary to eliminate one of the fronts at the time of initiation. This is done with comparative ease by establishing an incomplete partition. However, a fixed partition does not succeed always in guiding the detonation process in one direction. Sometimes the detonation gets through to the other side of the partition, and several fronts colliding with one another are formed.

A completely stable spread of the fronts in one direction is obtained with the aid of a mechanical shutter, which covers completely the entire cross section of the tube. The initiation of the detonating mixture takes place near one of the walls of the shutter. Synchronously with the initiation the shutter starts to open the channel and, at the time of the arrival of the detonation front from the reverse side, the section of the channel is completely open. The process of stationary detonation was photographed on a moving film with the aid of a photorecorder situated over the disk near the flat glass (Fig. #1). The photorecorder was installed in such a manner that the optical axis of the objective coincided with the axis of the ring-shaped channel. The image of the disk was disposed inside of the limits of the film. When the front of the detonation wave spreads along the ring-shaped channel, its picture on the moving film describes a cycloid. One of the photorecords obtained in this way is represented in Fig. 3.

A photorecord of detonation fronts spreading in various directions is given in Fig. 4. We can see on the photograph a regular, periodic picture of collisions of detonation waves.

It is necessary to note that stationary detonations are, as a rule, multi-headed, and that a solitary front can exist on the border of the detonation only.

We can observe five fronts, which rotate in one direction, on the photorecord shown in Fig. 3. The number of fronts in multi-headed stationary detonation is established at a maximum value and oscillates persistently around a constant quantity. It is easy to understand this, if we take into consideration that accidental elimination of one of the fronts increases the width and, thus, the stability of the remaining fronts. It is necessary to remember that each front is the base of a wedge formed by the original mixture. If the width of the front is at its maximum, then, after an accidental reduction in the number of fronts, the maximum width is reached ahead of at least one of the fronts, and this causes the re-establishment of the original number of fronts. In the contrary case, when the number of fronts increases over the constant quantity, weak, easily extinguishable fronts are formed, the widths of which are lower than the maximum; this produces a decrease in the number of the fronts down to the stable quantity.

Multi-headed stationary detonation thus represents a very stable process, insofar as the elimination of some of the heads causes an increase in the stability of the others.

A complex interaction of the fronts of impact arises around each of the detonation fronts.

We can get a general idea of this by taking the front AB in Fig. 2 as an example. The front butts its flank B against the feeding nozzle. The second flank of the detonation front, A, is not supported on the hard surface, and is lengthened in the form of an impact front in another medium, namely, in gas, that has burned out as a result of the passage of the preceding front. Transverse detonation waves, which are reflected by the hard wall at the point B but which escape at the point A into free space and get lost, extend behind the impact front AB.

The interaction of transverse detonation waves with another medium around the point A is very complex, and can be taken into account only with great difficulty. The task will be somewhat simplified if we consider the detonation front AB as an infinitely thin disruption of the gaseous state. In this case Prandtl-Meyer flow takes place in the detonation products which were formed behind the front AB. It is behind the line of rupture of the contact, which separates the detonation products from the gas previously burned, that the gas compressed by the impact wave AD flows.

Depending on the regime of the flow the front of this wave can start at point A, or somewhat before it if the deflection angle of the flow of the consumed gas exceeds the critical one.

The second flank D of the front of the impact wave AD ends in all cases at the external wall of the ring-shaped channel. It is necessary to note that the situation with the impact fronts in consumed gas, as described above, does not always occur but is observed only in cases when the number of fronts is small. The width of each detonation fronts, when the channel is filled with a new gas mixture during the rotation of one of the fronts, is $\frac{1}{n}$ times

the width of the channel. In the case of a multi-headed stationary detonation, when n reaches the value of 4-5, the energy which is liberated during the detonation of a narrow strip of fresh mixture, corresponding to one detonation front, is insufficient to create an impact wave in the entire cross section of the channel. In this case, a sound wave spreads through the consumed gas; it is not accompanied by entropy losses and it transmits the energy in the layer where the fresh mixture is located, with the small velocity of sound. After the mixture is consumed, energy is liberated, which in its turn supports the sound wave in the products consumed before.

Thus, when there are a great number of detonation fronts, they spread in the burned mixture with the velocity of sound. This kind of detonation process does not fit into the Chapman-Jouge system. A typical multi-headed stationary detonation is chosen in Fig. 3. The measured spreading velocity of the stationary detonation was equal to 1.4 km/sec, i.e., the same as the velocity of sound in combustion products. If we tighten the conditions under which the detonation takes place, for instance, by bringing the composition of the mixture close to the limits of detonation, or by narrowing the ring-shaped detonation channel, the number of heads will decrease and the velocity of the front will be close to normal, as calculated according to Chapman-Jouge.

Thus, the velocity of a stationary detonation grows with the worsening of the conditions governing its course and it must fluctuate between the limits of v_1 and $2v_1 = v_j$, where v_1 is the velocity of sound in the combustion products.

As to the appearance of the flame in stationary detonation, it is necessary to note that its color is blue-green, in contrast to yellow in the case of the normal combustion flame.

It is probable that the atoms of carbon do not have time, as a result of instantaneous combustion, to recombine into large groups, and this fact causes a fuller combustion of the detonation mixture. The course of the stationary detonation is accompanied by the emission of a monotonous sound of frequency nf , where n is the number of fronts and f is the frequency of rotation of each front.

In conclusion, the author considers it his duty to express his gratitude to academician M. A. Lavrent'ev for his interest in the present study.

The experiments were carried out by V. Tatarchuk and M. Tatarchuk.

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